

Seismic Analysis of Framed R.C. Structure with Base Isolation Technique using E-Tabs

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ABSTRACT

A Natural Calamity like an earthquake has taken a million lives throughout in our past. The force induced due to earthquake is dangerous and last for short duration of time. There are various techniques that can be used resist the force of an earthquake such as base isolation, bracing etc. The principle of base isolation is to isolate the structure from the motion of an earthquake and protect the structure and also reduce the force being transmitted to the building due to earthquake. For this study, (G+13) storied R.C. frame building is considered and time history analysis is carried out using E-Tabs 2017 software, and also study investigates structural behavior of multi-story building with or without base isolation subjected earthquake ground motion. The Lead Rubber Bearing (LRB) is designed as per UBC-97 code and the same was used for the analysis of base isolation system. Here we shall studying earthquake resistivity of structure by analyzing the base isolation structure to compare its structural performance with fixed base isolation.

KEYWORDS: Base Isolation, Lead rubber bearing, Time history analysis

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1. INTRODUCTION

Conventional Seismic design attempts to make building that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements and to some structural members in the building. The Idea behind base isolation is to detach (isolate) the building from the ground in such a way the earthquake motions are not transmitted up through the building, or at least greatly reduced.

There are different types of Isolation Components.

- A. Elastomeric Isolators
 - Natural Rubber Bearing
 - Synthetic Rubber Bearing
 - Lead Rubber Bearing

B. Friction Pendulum Bearing

Based on Sliding Surface Geometry, there are two types of sliding bearings, namely:

- I. Flat Slider Bearings
- II. Curved Slider Bearings

We Consider Lead Rubber Bearing Isolator for analysis, let us know some keywords on LRB

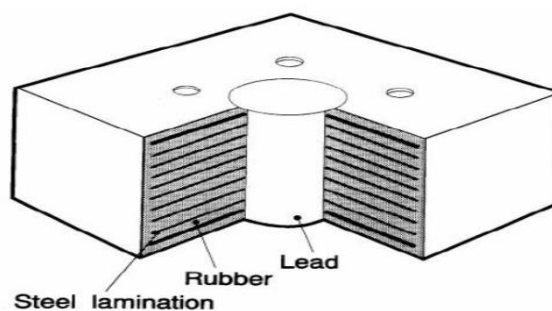


Fig-1: Lead Rubber Bearing

Lead Rubber Bearing consists of alternate layers of rubber and steel plates with one or more lead plugs that are inserted into the holes. The lead core deforms in shear providing the bilinear response and also provides the initial rigidity against minor earthquake and strong wind. The Steel plates in the elastomeric bearing gives large plastic deformations, So, an elastomeric bearing was then replaced by Lead plug and was tested. Lead rubber bearing represents an economical solution for the seismic isolation problems because it combines the functions of vertical support, of rigidity of service load levels, and of horizontal flexibility at earthquake load.

2. LITERATURE REVIEW

Many methods have been proposed for achieving the optimum performance of structures subjected to earthquake excitation. The use of Lead rubber bearing isolators for absorbing energy is the best technique. Many papers have been published related with base isolation technique as an earthquake resistant device. Some of them are discussed below.

Radmila B. Salic et al In this paper the authors have demonstrated the effect of dynamic response of the seven-story residential building under the earthquake ground motion. The fixed base model represents the dynamic behavior of the structure and seismic isolated model representing the dynamic behavior of the structure isolated by lead rubber bearing seismic isolation system. Dynamic analyses of both the model have been performed by E-tabs. Dynamic responses of fixed base and seismic isolated model have been calculated for four types of real earthquake time histories of different frequency characteristics whose value is determined based on detailed site response analysis. The authors have showed that increase of natural period of structure increases flexibility of the same structure. In seismic isolated model, base shear force is highly reduced. Increased flexibility of the system led to increase of the total displacements due to the elasticity of existing isolation.

V. Kilaret al In this paper four storey RCC building is designed according to Euro Code 8 for seismic analysis and dynamic performance evaluation. Different sets of base isolation devices are studied for investigation. First case is the use of simple rubber bearing and second one is the use of lead rubber bearing as a base isolation system. For the investigation of each system a soft, normal and hard rubber stiffness with different damping values were used. Non-linear pushover analysis was performed with the recent version of computer analysis software Sap2000. From this study it is concluded that the stiffer isolators with higher damping gives smaller target base displacements as compared to softer one with lower damping.

A. B. M. Saiful Islam et al In this paper a soft storey building is analyzed for seismic loading by creating a building model having lot of open spaces. The soft stories creates the major weak point in earthquake which means that during the event when soft storey collapses, it can make the whole building down. The research includes the placement of two types of isolators, first is lead rubber bearing (LRB) and second one is high damping lead rubber bearing (HDRB). Each storey is provided by isolators and its consequences were studied for different damping values. Finally, it has concluded that the flexibility, damping and resistance to service loads are the main parameters which affects for practical isolation system to be incorporated in building structures.

Di Sarno, et al has presented the structural analysis of the complex irregular multi storey RC frame used for the hospital building. It was carried out by means of modal analysis with response spectrum. The structure exhibits large mass eccentricity due to its irregularity in shape.

The building provided by circular shape high damping rubber bearing as per required diameter in accordance with Euro Code 8 to act as a base isolation system. The main objective of this study is to improve the earthquake resistant design approach by studying the properties like horizontal flexibility to increase structural period and reduce the transfer of seismic energy to super structure.

Juan C. Ramallo, et al In this paper authors have investigated the effects of using controllable semi active dampers, such as magneto rheological fluid dampers, in a base isolation system. A two degree of freedom model of a base isolated building is used. The fundamental concept is to isolate a structure from ground, especially in the frequency range where the building is most affected. The goal is to reduction in interstory drifts and floor accelerations to limit damage to the structure and its contents in a cost effective manner.

J. C. Ramallo, et al have presented an innovative base isolation strategy and shows how it can effectively protect the structures against extreme earthquakes without sacrificing performance during the more frequent, moderate seismic events. This innovative concept includes base isolation system with semi active or controllable passive dampers for the seismic response mitigation.

Pradeep Kumar T. V. et al has shown force deformation behavior of isolation bearings. In this paper the isolation bearing consists of isolators which increase the natural period of the structure away from high energy periods of the earthquake and a damper to absorb energy in order to reduce seismic force.

3. METHODOLOGY

By introducing the flexible layer between the foundation and the superstructure, the upper structure will act as a rigid body and the behaviors can be predicted by linear theory for 2-degree of freedom system. In order to obtain the behavior of isolation system, linear spring and linear viscous damping will be implemented to this simple 2-DOF system, linear spring and linear viscous damping will be implemented to this simple 2-DOF system model. The model shown in Figure 3.1 represents a rigid body sitting on a layer of flexible bearings.

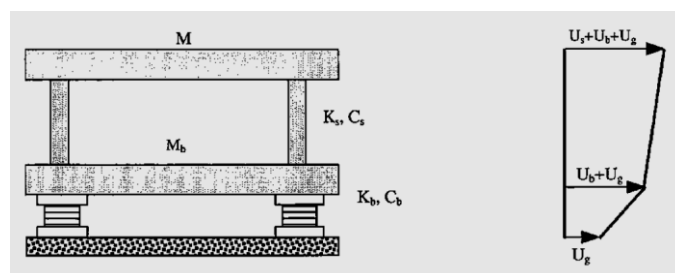


Fig 2: Parameters of 2-DOF Isolation Model

Where,

M, U_s = The mass and the shear displacement of the superstructure, respectively

M_b, U_b = The mass and the shear displacement of the base floor above the isolation layer

K_s, C_s = Structure stiffness and structure damping, respectively

K_b, C_b = Stiffness and damping of the isolation.

U_g = Ground Displacement.

The governing equation of motions is

$$m\ddot{u}_s + c\dot{u}_s + ku_s = -m(\ddot{u}_g + \ddot{u}_b)$$

For the fixed-based building, we can obtain the frequency and the fundamental period by following formulas:

$$W_f = \sqrt{\frac{K}{m}} \quad T_f = \frac{2\pi}{W_f} \xi_f = \frac{c}{2mW_f}$$

Where, W_f , T_f are the natural frequency and period, respectively, ξ represents the damping ratio. By including the stiffness and the damping of an isolation layer into a fixed-based building, we will obtain a new frequency and period of the isolated structures as follows.

$$W_b = \sqrt{\frac{k_b}{m+m_b}} \quad T_b = \frac{2\pi}{W_b} \xi_b = \frac{c_b}{2(m+m_b)W_b}$$

As a result of the much lower value of stiffness, we will obtain the new much longer period T_b with respect to fundamental period T_f of the building. The long period of vibration is the effective factor that reduces the force impacts to the structure. Linear theory equations and their derivations are detailed in "Design of Seismic Isolated Structures" by J.M. Kelly and "Introduction to Structural Motion Control" by J.J. Connor. The mode shapes of the building under linear theory can be determined as follows.

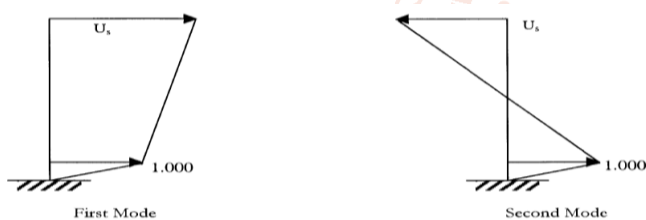


Fig 3: Mode Shape

In the calculation, by introducing the flexible layer to the foundation, it is clear that the response of the second mode is negligible in comparison with the first mode. The first mode reflects the dynamic response of the isolated floor while the structure above tends to act rigidly. The higher modes, which produce the floor interstory drift and accelerations, have very small participation factors. As a result, the high energy in the ground motion at higher frequencies cannot be transmitted to the structure. Given the fact that an isolation system redirects earthquake energy rather than absorb it, an isolation system doesn't depend on damping, although additional damping can be a supplemental tool to mitigate earthquake excitations.

Based on the fact that damping is not main factor in isolation efficiency, we did not include the effect of damping in previous analysis. Supplementing isolation with damping can provide a means of energy dissipation, and this is a second factor in reducing structural responses.

4. MODELLING IN ETABS

First select the proper units and arrange the grid system as per the plan. Draw the center line diagram of the

proposed building by providing the reference points and drawing the lines. Other method of modeling includes drawing center line diagram in AutoCAD save the file in.dxf Format. Modeling involves defining material properties, frame sections, for a said structure.

Table 1: Model Details

SI NO	Particulars	Description
1	Type of Frame	SMRF
2	No of Storey's	G+13
3	Height of Storey's	3
4	Height of Building	41.5m
5	Slab Thickness	200mm
6	Size of Column	(750 X 750)mm
7	Size of Beam	(230 X 450)mm
8	Wall Thickness	230mm
9	Concrete Grade	M30
10	Steel Grade	Fe 415
11	Specific Weight of RCC	25kN/m ³
12	Specific Weight of Infill	20kN/m ³
13	Type of Soil	Hard Soil
14	Response Spectra	UBC 97
15	Response Reduction Factor(R)	5.5
16	Importance Factor(I)	1

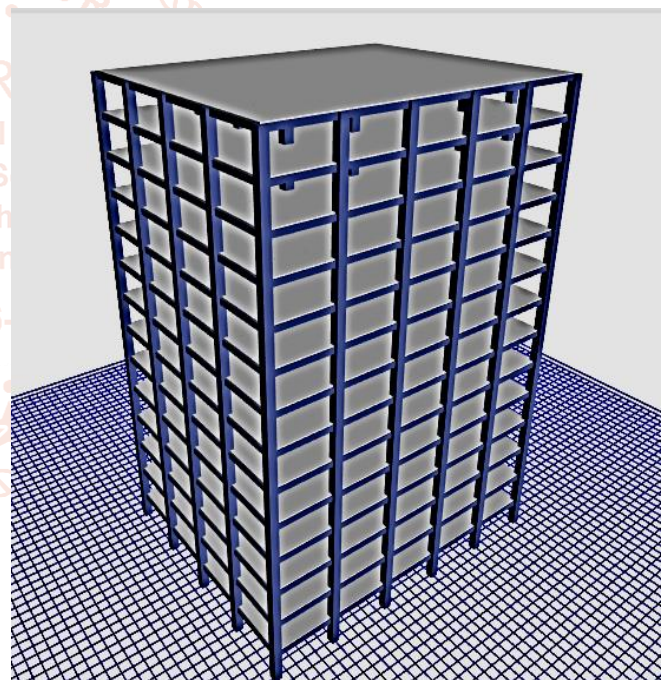


Fig 4: 3D Model of (G+13) building

5. DESIGN OF LEAD RUBBER BEARING ISOLATOR

➤ MANUAL DESIGN OF LRB ISOLATORS

The calculation of lead rubber bearing is carried out as follows:

1. The first step is to decide the minimum rubber bearing diameter depending on vertical reaction. This maximum vertical reaction obtained from analysis result of fixed base building which is found to be 6274.4738kN is considered as supporting weight LRBs.
2. Second step is to set the target period (2.5 seconds appears to be the desired one) and the effective damping β is assumed to be 5% for reinforced concrete structure according to IS 1893:2002 11 §7.8.2.1.

3. In third step, the spectral acceleration from the response spectrum graph in relation with the desired period is found to be 0.544.

4. In next step design displacement is calculated:

$$d_{bd} = \left(\frac{T_{eff}}{2\pi}\right) S_a$$

$$d_{bd} = \left(\frac{2.5}{2\pi}\right) \times 0.544$$

$$d_{bd} = 0.216m$$

Where,

$S_a = 0.544$, Spectral Acceleration

$T_{eff} = 2.5$ sec, Target Period

d_{bd} = Design displacement of isolator.

5. The required stiffness to provide a period is the effective stiffness:

$$K_{eff} = \left(\frac{2\pi}{T_{eff}}\right)^2 \frac{W_i}{g}$$

$$K_{eff} = \left(\frac{2\pi}{2.5}\right)^2 \frac{76676.7014}{9.81}$$

$$K_{eff} = 49371.25 \text{ kN/m}$$

Where,

T_{eff} = Effective fundamental period of the superstructure corresponding to horizontal translation, the superstructure assumed as a rigid body.

W_i = The weight on the isolator i.e. maximum vertical reaction.

K_{eff} = Effective stiffness of the isolation system in the principal horizontal direction under consideration, at a displacement equal to the design displacement d_{bd} .

6. E_D = Dissipated energy per cycle at the design displacement (d_{bd})

$$E_D = 2K_{eff}d_{bd}^2\beta$$

$$E_D = 2 \times 49371.25 \times 0.216^2 \times 0.05$$

$$E_D = 230.35 \text{ kN.m}$$

7. F_0 = Force at zero displacement under cyclic loading.

$$F_0 = \frac{E_D}{4d_{bd}} = \frac{230.35}{4 \times 0.216} = 266.61 \text{ kN}$$

8. K_{pb} = Stiffness of lead core of lead – rubber bearing

$$K_{pb} = \frac{F_0}{d_{bd}} = \frac{266.61}{0.216} = 1234.31 \text{ kN/m}$$

9. K_r = Stiffness of rubber in LRB

$$K_r = K_{eff} - K_{pb} = 49371.25 - 1234.31 = 48136.94 \text{ kN/m}$$

10. t_r = Total thickness of LRB

$$t_r = \frac{d_{bd}}{\gamma} = \frac{0.216}{1.5} = 0.144m$$

11. $D_{bearing}$ = Diameter of lead rubber bearing

$$D_{bearing} = \sqrt{\frac{K_r t_r}{400\pi}} = \sqrt{\frac{48136.94 \times 0.144}{400 \times \pi}} = 2.35m$$

Where.

$D_{bearing}$ = Diameter of lead rubber bearing.

t_r = Total lead rubber bearing thickness.

12. Total loaded area (A_L) calculation

D_{pb} = Diameter of lead core of LRB

$$D_{pb} = \sqrt{\frac{4F_0}{\pi\sigma_{pb}}} = \sqrt{\frac{4 \times 266.61}{\pi \times 11000}} = 0.176m$$

Where,

σ_{pb} = Total yield stress in lead, It is assumed to be 11Mpa.

Area of lead core in LRB

$$A_{pb} = \frac{\pi}{4} \times (D_{pb})^2 = \frac{\pi}{4} \times (0.176)^2 = 0.024m^2$$

D_{ff} = Diameter of force free section

$$= D_{bearing} - 2t$$

$$= 2.35 - 2(0.144)$$

$$= 2.062m$$

A_{ff} = Force Free Area

$$= \frac{\pi}{4} (D_{ff})^2 = \frac{\pi}{4} (2.062)^2 = 3.34m^2$$

A_L = Total loaded Area

= Force Free Area – Area of lead core

$$= 3.34 - 0.024$$

$$= 3.316m^2$$

13. Circumference of force free section

$$C_f = \pi \times t \times D_{ff} = \pi \times 0.144 \times 2.062 = 0.933m$$

14. Shape Factor = $S_i = \frac{\text{Loaded Area}}{\text{Circumference of force free section}}$

$$S_i = \frac{A_L}{C_f} = \frac{3.316}{0.933} = 3.55 = 4$$

14. H = Total Height of LRB

$$H = (N \times t) + (N - 1)t_s + 2t_{ap}$$

$$N = \frac{0.2}{t} = \frac{0.2}{0.01} = 20$$

$$H = (20 \times 0.01) + (20 - 1) \times 0.003 + 2 \times 0.04$$

$$= 0.337m$$

Where,

N = Number of Rubber layer.

t = Single rubber layer thickness = 0.01m

t_s = Thickness of steel lamination = 0.003m

t_{ap} = Laminated anchor plate thickness = 0.04m

15. Bearing horizontal stiffness (K_b)

$$K_b = \frac{GA_r}{H} = \frac{700 \times 0.138}{0.337} = 286.65 \text{ kN/m}$$

Where,

G = Shear modulus (Varying from 0.4 to 1.1Mpa)

A_r = Rubber layer area = 0.138m²

H = Height of LRB = 0.337m

16. Total bearing vertical stiffness (K_v)

$$K_v = \frac{GS_i^2 A_r K_6}{(6GS_i^2 + k)H}$$

$$K_v = \frac{700 \times 4^2 \times 0.138 \times 2000 \times 10^3 \times 6}{(6 \times 700 \times 5^2 + 2000 \times 10^3) \times 0.337}$$

$$K_v = 26.6 \text{ MN/m}$$

Where,

S_i = Shape Factor = 5

K = Rubber Compression modulus = 2000Mpa.

From above calculation summary of lead rubber bearing design for symmetric building is as shown in Table 1

Table 2: Summary of LRB parameters

1. Required Stiffness (K_{eff})	49371.25 kN/m
2. Bearing horizontal stiffness (k_b)	286.65 kN/m
3. Vertical Stiffness (K_v)	26.6 MN/m
4. Yield Force (F)	266.61 kN
5. Stiffness Ratio	0.1
6. Damping	0.05

➤ BASE ISOLATION CALCULATION IN ETABS

Design the LRB isolator according to UBC-97 using the Maximum Vertical Load

- Maximum Vertical Load Column Support, $W=6274.4738$ kN
- Shear Modulus, $G=0.7$ N/mm² (Mpa)
- Design Time Period, $T_D=2.5$ sec
- Seismic Zone Factor, $Z=0.2$ (UBC-97, Vol-2, Table 16-I & Zone Map)
- Seismic Source Type = B
- Near Source Factor, $N_a=1$ (UBC-97, Vol-2, Table 16-S)
- Near Source Factor, $N_v=1$ (UBC-97, Vol-2, Table 16-T)
- $ZN_v=0.2$
- Maximum Capable earthquake response coefficient, $M_m=1.5$ (UBC-97, Vol-2, Table A-16-D)
- Soil Profile Type = S_c (UBC-97, Vol-2, Table 16-J)
- Seismic Coefficient, $C_v=C_{vD}=0.32$ (UBC-97, Vol-2, Table 16-R)
- Seismic Coefficient, $C_a=0.24$ (UBC-97, Vol-2, Table 16-Q)
- Choose Response Reduction Factor, R for =5.5 (UBC-97, Vol-2, Table 16-N)
- For SMRF/IMRF/OMRF, Structural System =2 (UBC-97, Vol-2, Table A-16-E)
- Effective Damping (β_d or β_m) =5%
- Damping Coefficient (B_d or B_m) =1 Interpolate (UBC-97, Vol-2, Table A-16-C)
- Design Displacement, $D_d=0.1989$ m

$$D_D = \frac{g C_{vD} T_D}{4\pi^2 B}$$
- Bearing Effective Stiffness, $K_{eff}=4035.97$ kN/m

$$K_{eff} = \frac{W}{g} \times \left(\frac{2\pi}{T_D} \right)^2$$
- Energy Dissipated per Cycle, $W_D=50.18$ kN-m

$$W_D = 2\pi K_{eff} D_D^2 \beta_{eff}$$
- Force at Design Displacement or characteristic strength, = 63.046 kN

$$Q = W_D / 4D_D$$
- Pre Yield in Rubber, $K_2=3719.14$ kN/m

$$K_2 = K_{eff} - Q/D_D$$
- Post Yield Stiffness to Pre Yield Stiffness Ratio (η) for Rubber =0.1

$$\eta = K_2/K_1$$
- Post Yield Stiffness (Value for Non-linear Case also), $K_1=37191.43$ kN/m
- Yield Displacement (Distance from End-J), $D_Y=0.00188$ m

$$D_Y = Q/(K_1 - K_2)$$
- Recalculation of Force Q to $Q_R=63.6484$ kN

$$Q_R = \frac{W_D}{4*(D_D - D_Y)}$$
- Yield Strength of Lead, =10 Mpa

- So, Area of lead Plug Required. $A=0.006365$ m²

$$A_{PB} = Q_R / 10 \times 10^3$$
- So, Diameter of Lead Plug Required, $d=0.090045$ m = 90.045 mm
- Recalculation of Rubber Stiffness K_{eff} to $K_{eff(R)}$ = 3716.1158 kN/m

$$K_{eff(R)} = K_{eff} - Q_R/D_D$$
- Maximum Shear Strain of Rubber, $\gamma=100\%$
- Total Thickness of Rubber, $t_r=0.198994$ m

$$t_r = D_D / \gamma$$
- Area of Bearing, $A_{LRB}=1.0564$ m²

$$A_{LRB} = \frac{K_{eff(R)} * t_r}{G}$$
- Diameter of Bearing, $D_{LRB}=1.1600605$ m = 1160.06 mm
- Horizontal Time Period Consider =2 sec (Taking horizontal period to be 2sec)
- Horizontal Frequency, $f_h=0.5$ Hz

$$f_h = 1/2 = 0.5$$
 Hz
- Set Vertical Frequency, $f_v=10$ Hz
- So, Shape Factor, $S=8.3333$

$$S = (1/2.4) * (f_v/f_h)$$
- Single Layer of Rubber, $t=34.8018$ mm

$$t = \phi_{LRB} / 4S$$
- So, Number of Rubber Layer, $N=5.718 \sim 6$
- So, Provide Single layer of Rubber = 25 mm (Round up to nearest 5)
- Let, Thickness of Shim Plates =2.8 mm
- Number of Shim Plates, $n=5$ $n=N-1$
- End Plate Thickness is between 19mm to 38mm, Choose =25 mm
- So, Total Height of LRB, $h=214$ mm
- Bulk Modulus, $K=2000$ Mpa
- Compression Modulus, $E_c=249131.94$ kN/m²

$$E_c = 6GS^2 (1 - (6GS^2/K))$$
- Horizontal Stiffness, $K_H=3716.1158$ kN/m

$$K_H = GA_{LRB}/t_r$$
- Vertical Stiffness, $K_v=1256557.836$ kN/m = 1256.5578 MN/m
- Cover From Lead to End Plate = 25 mm
- Bonded Diameter = 1.11006 m
- Moment of Inertia, $I=74496559729$ kN/mm

$$\text{Cir: } I = \pi B^4/64 = 0.07449656$$
 kN/m
- Area of Hysteresis Loop, $A_h=49.708$ kN/m

$$A_h = 4Q (D_d - D_y)$$
- Yield Strength, $F_y=70.051$ kN

$$F_y = Q + K_2 * D_y$$

Reference: UBC-97 & DESIGN OF SEISMIC ISOLATED STRUCTURE FROM THEORY OF PRACTICE by JAMES M.KELLY and FARZAD NAEIM

Final input values for ETABS

Table 3: Summary of LRB Parameters in E-tabs

Rotational Inertia	0.074497 kN/m
For U1 Effective Stiffness	4035967 kN/m
For U2 & U3 Effective Stiffness	4035.967 kN/m
For U2 & U3 Effective Damping	0.05
For U2 & U3 Distance From End J	0.001884m
For U2 & U3 Stiffness	37191.43 kN/m
For U2 & U3 Yield Strength	70.05101 kN

6. RESULT OBTAINED FROM ETAB SOFTWARE

All results are computed after analysis of model in software E-tabs 2017.

Result Obtained From Seismic Load Calculation

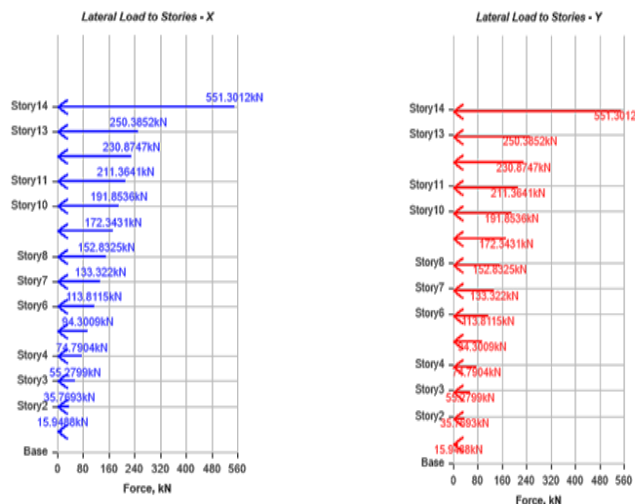


Fig 5: Applied Storey Force in Both X & Y Direction (Fixed Support)

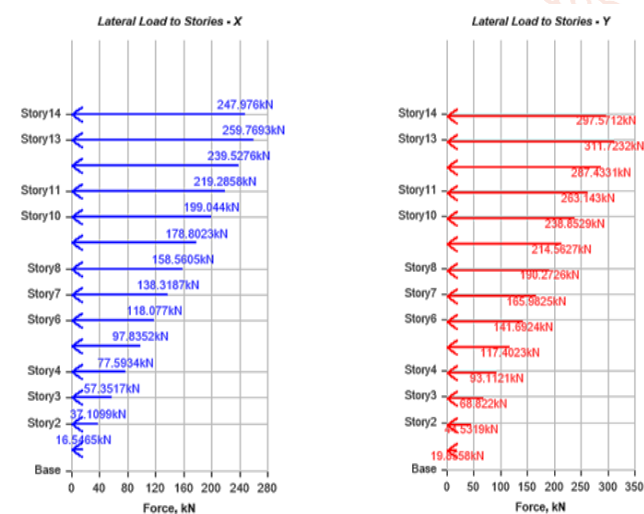


Fig 6: Applied Storey Force in Both X & Y Direction (Base Isolation Support)

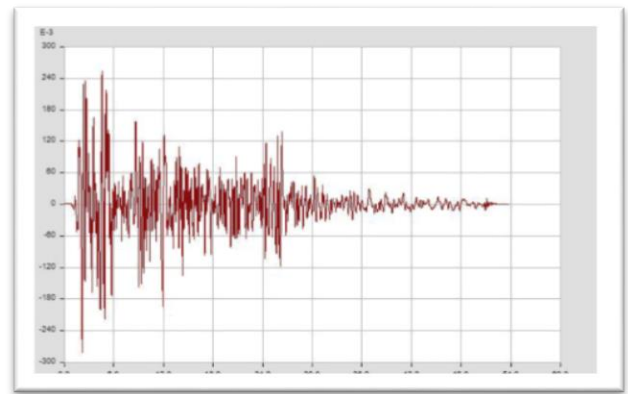


Fig 7: Details of el-centro Earthquake in X-180

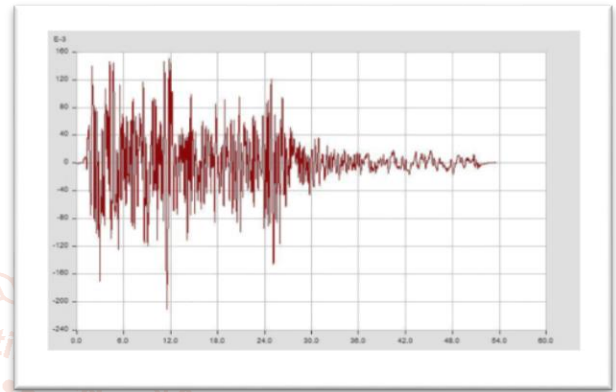


Fig 8: Details of el-centro Earthquake in Y-270

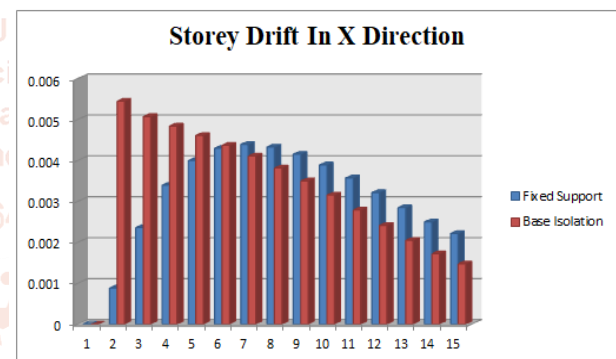


Fig 9: Storey Drift in X-Direction

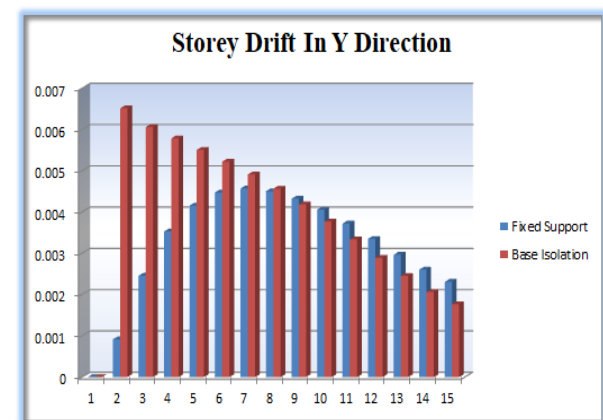
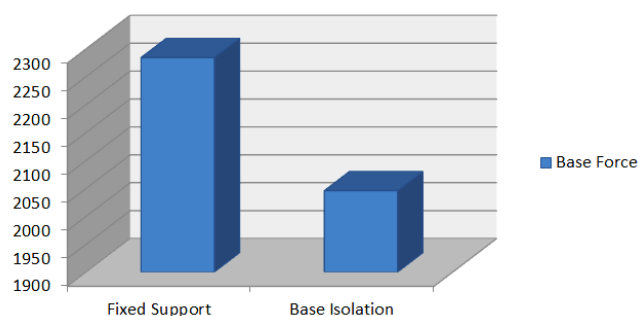
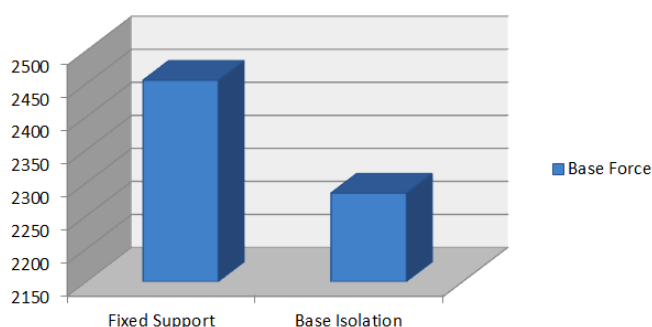
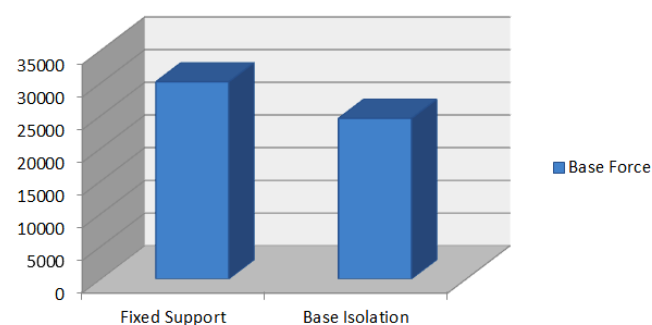


Fig 10: Storey Drift in Y-Direction

Base Force along X Direction**Fig 11: Base Force along X-Direction****Base Force along Y Direction****Fig 12: Base Force along Y-Direction****Moment along Z Direction****Fig 13: Moment along Z Direction****CONCLUSION**

- Improvement of base isolation system under extreme excitations, such as
 - Reduction in Storey Drift in both X and Y direction
 - Reduction in Base Force in both X and Y direction
 - Reduction in Moment along Z direction
- When referring the consideration of the designed building subjected to service load, semi - active control is a preferred alternative that can reduce the response of the building and does not have large power requirement. By adjusting the mechanical properties, such as stiffness and damping, the performance of base - isolated building can be improved under low power excitations.
- It has been observed that maximum shear force, bending moment, storey acceleration, base shear decreases; whereas increase in lateral displacements

were observed for bottom storey of base isolated building as compared with fixed base building model.

- From analytical study, it is observed that fixed base building have zero displacement at base of building. Whereas, base isolated building models shows appreciable amount of lateral displacement at base.
- Floor Height increases lateral displacement increases drastically in fixed base building as compare to base isolated building. Due to this reduction in lateral displacement during earthquake damages of structural as well as non-structural is minimized.
- At base more storey drift was observed for base isolated model as compared to model of fixed base building. As storey height increases, the storey drifts in base isolation building model drastically decreases as compared to model of fixed base building.

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